COMPOSITION AND GEOCHEMICAL EVOLUTION OF EUROPA'S ICY SHELL. J.S. Kargel, U.S. Geological Survey, 2255 N Gemini Dr., Flagstaff, AZ 86001, U.S.A. (email: jkargel@usgs.gov).

Introduction: The *Galileo* project's discovery of imaging, spectroscopic, and geophysical evidence pointing to the existence of an ice-covered ocean on Europa stands among the most stunning scientific and philosophical achievements of the Space Age. Europa, a geologically dynamic water world, runs even with Mars as a place where life may now or have once existed. In one respect, Europa is a better bet than Mars for current life: Europa presently has an ocean, whereas the longevity of vigorous hydrologic systems on Mars is still subject to debate. However, aside from the fairly certain conclusion that Europa now has an ocean, our knowledge of Europa remains scanty by comparison to what we know of Mars. The floating shell's composition is not reliably known. Each of several geochemical models has vast implications for Europan shell dynamics. I shall review divergent compositional interpretations of spectroscopic/imaging data and models of compositional evolution, and draw logical implications for shell structure and dynamics.

Some big controversies

The bizarre beauty of Europa arises from the coupled geological and geochemical dynamics of the icy shell and ocean. How this coupling is achieved and what processes occur unknown; ideas are plentiful. Two far-reaching current debates concern: (1) the physical dynamics of the floating shell (thick shell vs. thin shell debate and solid-state convection versus melt-through), and (2) the geochemical dynamics of the floating shell (including interpretations of the non-ice material: is it hydrated sulfate salts, hydrated sulfuric acid, or hydronium ice?). Probably nobody understands Europa's reality very well; the reality may encompass some of what each group has supported. The debates are not going to be solved until we have a new Jupiter/Europa mission designed to resolve the disputes. In the mean time, further work is warranted, because the observations, models, and arguments will shape the experiments and observational capabilities needed for future missions and will better frame the interpretations once we obtain new observations.

Imaging clearly indicates that Europa's physical shell dynamics are coupled to geochemistry; but nothing so far has proven how this coupling is accomplished. I review some published ideas below and offer some new ones about the coupling. *Each idea upholds a significance of the mysterious non-ice "red stuff."*

To deflect unintended impressions that anybody actually understands Europa, I offer the following schedule of ideas. My sense is that we know as much about Europa now as we knew of Mars after *Mariner 9* (not so much, except how exciting it is).

Dynamic daily thinking

Monday's exogenous thought: the cell stain hypothesis. The icy shell of Europa is nearly pure ice. A red stain comes externally by implantation of magnetospheric plasma into ice and UV and particle radiation damage of ice. Staining is controlled by geologic structures and geography. Factors include: (i) heterogeneous distribution of mineral grain size and grain fabric (such as anisotropy), (ii) microtectonic fabric (such as ice strain and microfracturing), (iii) cumulative radiation damage (and age) of the ices, (iv) partial local topographic shielding and regional (latitude/longitude) control of the magnetospheric flux, and (v) temperature variations related to latitude and albedo. These factors cause differential retention and processing, loss to space, burial, or concentration of the products of exogenic alteration of ice and implanted exogenous species. Thus, Europa's structured surface is like a structured cell, which absorbs stains differentially, thus making visible cellular organelles and other subcellular structures. If Europa's icy shell is nearly pure ice, it may have originated by heterogeneous accretion or by efficient fractional crystallization of an ocean and brine drainage from ice.

Tuesday's endogenous thought: The invisible ink hypothesis. The floating shell may be nearly all H_2O, but the red stuff is emplaced as uncolored trace impurity. The stain, like invisible ink written onto the surface from below, has an endogenic origin. Diapiric structures, partial melting, intrusions, brine drainage, fractional crystallization, and explosive gassy eruptions redistribute and fractionate the stain and partly segregate it from ice. Charged particles, UV, and cosmic rays color the stain, which may be a trace sulfate (salt or acid); it may be related to the ocean or not.

Wednesday's hump thought: we might never make it to the end of the week. Without in-situ data we will not resolve exogenous and endogenous sources of the red stain, because it is chemically disequilibrated material. With both high-temperature suboceanic processing or radiation processing it all looks the same.

Thursday's humbling truth revealed? The "it's not just red barn paint" hypothesis. The red substance looks so bold on the surface because it is fundamentally a major component of a chemically complex floating shell. Whether intrinsically red or dyed by exogenic alteration, the physics of the icy shell and viability of the ocean as a habitat is affected. It is probably a sulfate (hydrated sulfate salts or hydrated sulfuric acid). But that is not all. It is a heterogeneous mixture, perhaps short-chain sulfur, sulfuric acid, and sulfate salts; maybe add to that traces of arsenic minerals (e.g., realgar and orpiment), selenium, and sulfur phosphides. Sulfates and other soluble components may have been derived either from low-temperature or high-temperature aqueous alteration of the rocky interior of Europa. Solutes affect the melting point, density, viscosity, and thermal conductivity of the icy shell. It is central to issues of melt-through, diapirism, and tidal heating. Reaction products may have accumulated on the seafloor, and others may have floated to the base of the icy shell. Little about Europa can be understood without understanding this material.

Friday's party thought: Europa has an "Io" lurking below its ocean. The red substance comes up from below and is intrinsically red. Europa vents sulfur dioxide and Pele-plume-like red stuff into the ocean, where it quenches and eventually vents onto the surface or upwells through the ice. We can learn much about Europa by understanding Io.

Saturday's escape to the mountains: Whatever the red substance may be, the surface elemental, molecular, and mineralogical composition of Europa's surface can be tightly constrained by Earth- and Earth-orbit-based astronomical observations. We can then better constrain and model *Galileo's* observations. Top priority should be astronomical studies of charged ionic and neutral atomic/molecular particles emanating from Europa. Such studies may provide the only fundamental, new Europa observations for a long time.

Sunday's hope: Any Europa orbiter ought to be capable of (1) multispectral discrimination of sulfurous chromophores, and (2) neutral and ion spectroscopic determinations of elements from hydrogen through the masses at least of arsenic and selenium. The mission design should allow Europan and Ionian emanations to be distinguished.

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